

# CASEBOOK

OF

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## A NEW VIEW OF MAGNETIC FIELD

Our entire theoretical conception of magnetic field in empty space was formed, and cast in bronze, in an epoch when our observational knowledge of magnetic field in the universe was but a minute fraction of what it is today.

Subsequent observations, such as the spectacular manifestations of cosmic magnetic field, were force-fitted into that 'childhood' conception - without any second thoughts whatsoever.

## PREAMBLE

Magnetic field may be mankind's earliest introduction to what is today modern physics. It may also be the primal and the ultimate essence of the universe. It seems also to be the one concept we have got altogether wrong. This would place the entirety of modern physics at issue. The shocking thing is that today's physics establishment has proved itself woefully inadequate to even begin to understand the situation, and so to rectify it.

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James Clerk Maxwell and his contemporaries in that epoch gave us a technical description and a working definition of magnetic field. Maxwell and earlier Michael Faraday specifically stated that they had not understood its physical nature. I, for the first time in history, have attempted to describe the physical nature of static magnetic field in empty space.

*What is it in itself?*

*What is its nature?*

# *Chapters*

**I. FROM HUANG DI TO PRESENT DAY: A WRONG HAUL?**

**II. MATHEMATICAL ENTITY vs REAL ENTITY**

**III. THE PRESENT VIEW**

**IV. MAGNETIC FIELD IN THE LABORATORY**

**V. MAGNETIC FIELD IN NATURE**

**VI. A CHOICE AND ITS CONSEQUENCES**

**VII. A DEFINITION AND ITS CONSEQUENCES**

**VIII. IF HISTORY WERE ANY GUIDE...**

**IX. PARADOXES OF GRAVITATION AND COSMIC MAGNETIC FIELD**

**X. THE SURVEYOR'S PARADOX**

**XI. CONSIDERATIONS OF EXPERIMENTAL VERIFIABILITY**

**XII. CLOSING THOUGHTS**

**APPENDIX A: IMAGES**

**APPENDIX B: A REFEREE REPORT REJECTING THE PAPER**

**APPENDIX B: THE PAPER**

# CHAPTER I

## FROM HUANG DI TO PRESENT DAY: A WRONG HAUL?



*Ancient Chinese Emperor Huang Di is said to have discovered magnetism 4700 years ago*

The history of magnetism may date back to the time of Chinese Emperor Huang Di (c. 2700 BC) who used a magnetic rock as a compass. The modern view of magnetic field dates back to the nineteenth century when the scientific and mathematical foundations of the subject were laid. Also, our basic understanding of magnetic field is thought to have been complete at this time. Everything that followed since, including modern space research, represents applications of that understanding.

What is it that assures us that a basic scientific concept, even if long-entrenched, is the correct concept? Basically, three things:

- (1). The understanding correctly explains observations made.
- (2). The understanding correctly predicts observations yet to be made.
- (3). The understanding offers no difficulties over a long period of application.

Our pre-Einsteinian understanding of gravitation would meet these three criteria. Yet we know today that this understanding was incomplete. Our pre-

Quantum Theory understanding of light would fit these three criteria. Yet we know today that this understanding was incomplete.

The point is this: A certain idea may serve well for a long time, until some difficulty – even if subjective difficulty – surfaces. Then it is ready for a new assessment.

I am questioning the present understanding of magnetic field. But one might say: The present understanding of magnetic field works fine – there are no problems with it! This is a good logic if you are arguing against replacing an old automobile with a new one. But not in science. Never in science.

## CHAPTER II

# MATHEMATICAL ENTITY vs REAL ENTITY

As we set out on this most unusual scientific exploration, we need to hold clear in our minds the distinction between a mathematically defined entity and a real entity. A mathematically defined entity is an imaginary concept. A real entity is something you can directly or indirectly touch or feel or otherwise sense. Consider these examples:

- If I ask you to imagine an elliptical orbit in space, I am asking you to consider a mathematical entity. If I say I feel a draft, I am telling you about a real entity.

- In a class of 21 students, one can mathematically define a student with average height and a student with median height. Both are mathematical entities. The former has no reality, but may have helpful uses. But the latter is also a physical entity: It is a particular student Fred Smith.

- The equation for a spacecraft trajectory describes an imaginary line (mathematical entity). But the equation for a vibrating string describes a mathematical curve as well as a real thing: the sinuous string.

We can proceed to physics-linked examples as well. The concept of a black hole at first is a purely mathematical concept (“singularity”). But a whole scientific industry has evolved around it to give this mathematical concept physical reality. The issue remains controversial, and has brought to the fore again the rudimentary issue of what is real and what is fictitious.

With this orientation in mind, we will study below the definition of a *magnetic field*. Then we will ask: Is this magnetic field a mathematical entity or a real entity?

This question sums up the entire thrust of this report.

## CHAPTER III

### THE PRESENT VIEW

In present view, magnetic field in empty space is first a theoretical concept and second, a mathematical definition. The theoretical concept is this: When a bar magnet exerts a force on a compass needle (say), there appears to be occurring an "action at a distance". It is as though something is conveyed from the magnet to the compass through the intervening empty space. But without asking what this something is, one can say in loose language that there exists around the bar magnet a region of influence, called its *magnetic field*. A compass needle placed in that region will respond accordingly. In theory, this region of influence extends out to infinite distances in all directions.

The nature of this influence can be visualized as follows: On a plane sheet of paper, place a bar magnet. Then place a tiny compass needle at various locations, and mark a tiny arrow to represent the needle's position and orientation. When a large number of such arrows have been plotted, one begins to see that there appear to be gently curving lines connecting the North pole of the magnet to the South pole. These are the conceptual *magnetic field lines*. I have not studied up on the actual history of emergence of this concept, but it seems generally that it dates back to the epoch of James Clerk Maxwell. Certainly, Maxwell made extensive use of them as a thinking aid.

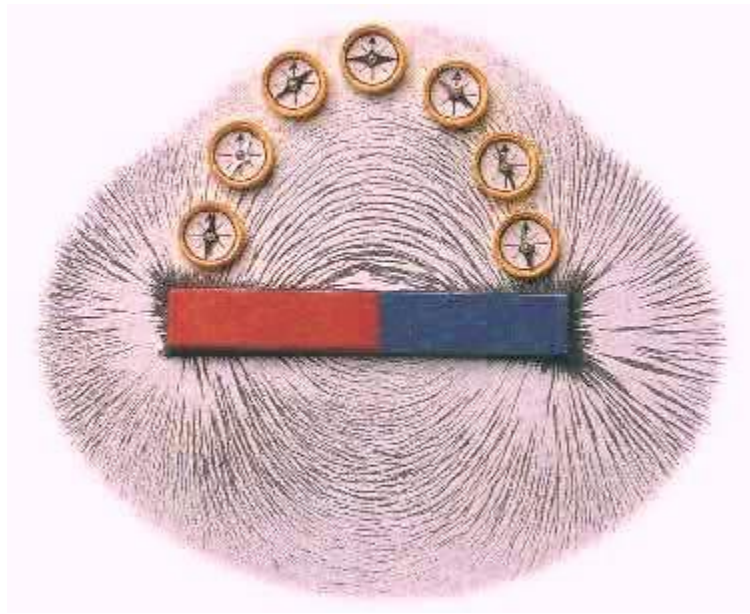
Now to the mathematical definition: Its purpose is to quantify the influence of the magnet at various locations within its region of influence. Through the experience of studies such as described above, one learns that the compass needle always aligns itself to be tangential to the field line. And the lines are more crowded where the force of alignment is stronger. From these observations, the following mathematical definition, verifiable in other ways, has emerged: The magnetic field at any point is tangential to the magnetic field line at that point, and the strength of the field is proportional to the number of field lines per unit cross-sectional area perpendicular to the field lines there.

These are the basic ideas. One can put them in mathematical language, and manipulate them for various purposes. Here we want to stay away from mathematical symbols and expressions and equations as much as possible. Here we want to *think*.

## CHAPTER IV

# MAGNETIC FIELD IN THE LABORATORY

A striking visualization of magnetic field is the simple high school experiment already outlined above. Lay out a piece of white paper on the table, place a bar magnet on it and draw the rectangular outline of the magnet (marking the North and the South poles at the two ends, within this rectangle). Then take a compass needle that is much smaller in size than the bar. Place the needle near one pole, mark two dots corresponding to the point and the tail of the compass needle. Then move the needle away from the pole so that your next tail dot will be the current point dot. If you continue this process accurately, the needle will end up at the corresponding location near the other pole. Connect all the dots, and you have a magnetic field line. Draw many such lines, and you have mapped the magnetic field.



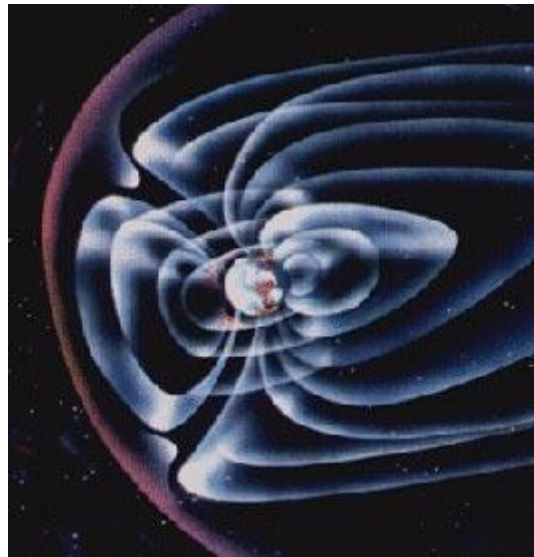
*Magnetic field visualization [Courtesy: [www.school-for-champions.com](http://www.school-for-champions.com)].*

A lazy person's alternative to the above experiment is this: Take away the compass needle. Sprinkle some iron filings on the paper. Then gently tap the table. You will see that the iron filings will align themselves to visualize the magnetic field map. Although it has the appearance that the field lines are now a real thing (iron filings), an appearance is all it is. Magnetic field lines are still mathematical entities.

## CHAPTER V

# MAGNETIC FIELD IN NATURE

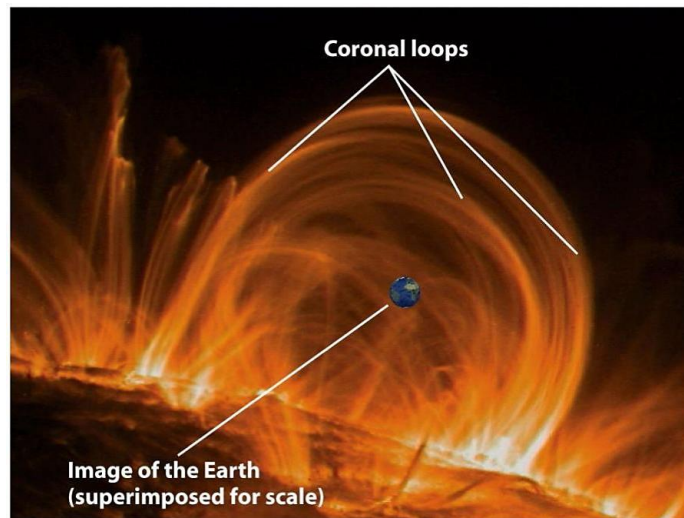
With this picture in mind, you can now move to a very grand arena and see almost exactly the same thing in nature. We are speaking of course of the planetary magnetic field. The planets such as the Earth and Jupiter are much like this bar magnet: It is as though they have such magnets at their core. How these magnets come to be there is another subject we are not concerned with here.



*Visualization of the magnetic field system for the solar wind-magnetosphere interaction:*

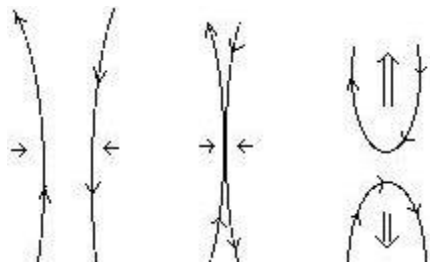
*Intuitively, does this seem like the work of a mathematical entity?*

Now we need to discuss another property of magnetic field lines. (Note that we said earlier that a magnetic field line is only a mathematical definition and not a real thing, but we already start to talk about "property of magnetic field line"! It is like discussing the properties of the Tropic of Cancer.) Charged particles, like electrons and positive ions, cannot readily move *across* a magnetic field line. They can move fine *along* the field lines. In the cosmic arena, these charged particles will take the place of the compass needle in helping us visualize magnetic field lines. The point to remember here, for later discussion, is that a charged particle's motion is constrained by a magnetic field, but a neutral particle's (an atom or a molecule) is not.



*Spectacular display of magnetic field effect in the solar atmosphere: Intuitively, does this seem like the signature of an abstract entity?*

Thus when the solar wind (made up of charged particles) move towards the Earth across the latter's magnetic field, it reaches a point where the Earth's magnetic field is strong enough to prevent these particles from coming in any further. These particles then flow around, and along the magnetic field lines towards the Earth's poles. This, in essence is the physics of the planetary magnetospheres – whose existence is well established by observations. A picture of the magnetosphere is perhaps the most spectacular visualization of magnetic field lines.



*Magnetic field line "reconnection": These theories, mostly applied to the natural world (solar atmosphere etc.), say that field lines get torn apart and then connect up the "wrong" way. Try and reconcile this picture with the field being only a mathematical definition!*

Another remarkable example from nature is the solar magnetic field. However, here we are no longer dealing with a bar magnet-type field, but something more complicated. Actually, this is a good place to clarify something else about magnetic fields at astronomical scales. They generally derive from two sources. Consider, for example, the region where the solar wind impinges on the Earth's magnetosphere. A part of the magnetic field here is clearly the remote field of the Earth. But there is

another part that is resulted from local electric currents flowing in the plasma there. What we see in the visualization is the sum of these two fields. The field in the solar atmosphere is also of the same nature.

To summarize at this point: We have covered two important aspects of the present understanding of magnetic field –

*Magnetic field lines:* There is no such thing as a magnetic field line. It is only a mathematical definition.

*Visualization:* The mathematically defined field lines can be visualized in the laboratory. They can also be visualized in a drawing of the observed magnetosphere. They are visualized by luminous plasma in certain photographs of solar photosphere, and possibly also distant galaxies.

Such visualizations, and many others involving motion of the visualized field lines, are so dramatic that they convey a sense of reality of the magnetic field lines. It is as though they are real ropes or strings or hammocks strung out in space. Physicists exploit this imagery in the process of forming their ideas. Nevertheless, in the prevailing view, magnetic field lines are completely imaginary mathematical abstraction.

This point is very important. If you try to discuss this with any contemporary researcher in the field, you may not get a straight response. In TV comedy, sometimes you see pranksters who have learned to speak in a continued stream of elegant, correct and ornate sentences – in a coherent fashion. Only if you are paying close attention do you realize that they are not actually saying anything meaningful – just complete nonsense. That is what is happening with today's experts when it comes to the true nature of magnetic field. The difference is that, in the latter instance, it is unintended comedy.

## CHAPTER VI

### A CHOICE AND ITS CONSEQUENCES

The idea presented in this essay is not a 'curve ball', but a most logical and most natural outgrowth of the history of physics. The only element of surprise is why this idea was not considered a long time ago. The problem we have when we deal with the concept of *instantaneous* 'action at a distance' between two points A and B is the problem of time it takes for light to travel between A and B. That is, if we accept that this is the fastest speed at which two objects can influence each other - in whatever mode or manner. As long as we are concerned with small distances AB, as in the case of the force between two compass needles on a table, the travel time does not manifest itself as a problem. But as soon as AB is as large as, say, the radius of Jupiter's magnetosphere, it is a problem. It is the same problem as that which caused Einstein to formulate his view of gravitation. Therefore, as soon as we discovered that the influence of a magnet existed over such large distances, we needed to reconsider our view of magnetic field. It was really this simple. And needless to say, when you reconsider something, then you have to ask: If it is not this, then what is it?

Consider now an electron at a location O in the magnetic field of Jupiter's outer magnetosphere. The location O is at a distance R from the center of the planet. The electron trajectory is influenced by the planetary magnetic field at O. Now suppose that somehow the magnetic field of Jupiter suddenly (instantaneously) ceases to exist. What then happens to the electron orbit? There are now two conflicting scenarios, both dictated by the laws of physics:

*Physics scenario A:* Since the source of the magnetic field is gone, its mathematically defined field at O is also gone instantly. So the electron motion changes instantaneously to one where there is no magnetic field.

*Physics scenario B:* There is involved a certain travel time. At the instant the magnetic field disappears, the electron has no knowledge that anything has happened. The "news" of the disappearance has to travel to the electron before it changes its motion. This news can travel only as fast as the velocity of light, c. Thus, a time  $R/c$  must pass before the electron trajectory will change. During this period, the electron moves as though nothing has happened.

In the Scenario A, an observer at O can learn about the disappearance of Jupiter's field at infinite speed. This is unphysical.

In the scenario B, this same observer learns of the disappearance at the speed of light.

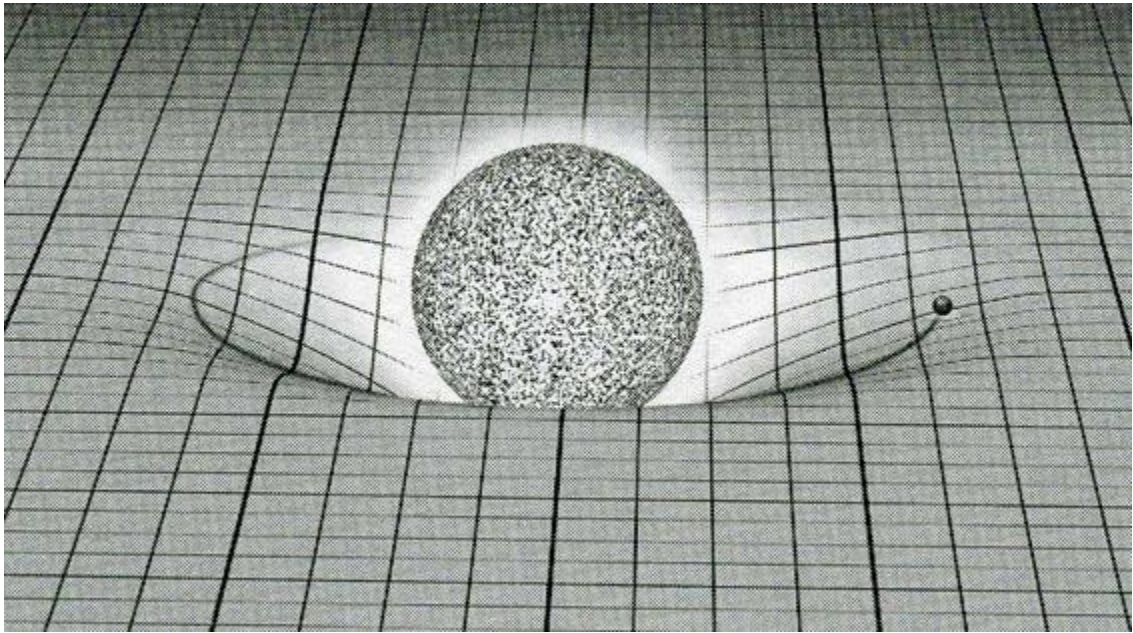
Therefore, the Scenario B is correct. However, as soon as we choose B over A, we have to face all the consequences of this choice.

What this means is that something remains at O even after its source (Jupiter's magnetic dipole) has disappeared. This in turn means at the magnetic field at O was always a real something, and not a mathematical entity. Something physical had been *emplaced* at O – and it continues to remain there until the news reaches that its source is gone.

Recall that thinking about a "paradox" much like this caused Einstein to formulate his theory of gravitation. In his case, one was dealing with the gravitation instead of magnetism. In the above example, imagine Jupiter to be the Sun, and the electron to be a planet orbiting around the sun. Then suddenly, the Sun disappears, and the source of gravitational attraction is gone. What happens to the planet? Does it instantly go off the orbit? No, Einstein's answer is that it stays in the orbit for a time  $R/c$  before going off. It is as though gravitation continues to operate on the planet at its location even though the Sun is gone. Something was "emplaced" at the planet's location. Einstein explained this by proposing that the Sun had modified *the space itself* around it, and that "distortion" of space at the planet's location continues to remain until the news of the Sun's disappearance reaches there. What was emplaced was a local modification of the space around the planet.

It should now be absolutely clear that there is a serious problem with the present view of magnetic field as just a mathematical definition. For magnetic field, however, I do not automatically follow Einstein to propose a similar distortion of space. Instead, I explore *from first principles* what it was that was emplaced.

But, even if the above consideration is important for gravitation, is it important for magnetic field? Actually, it is more important for magnetic field. On a cosmological scale, gravitation and magnetic field are equally important influences. On the scale of atomic and subatomic particle, magnetic field is far more important than gravitation. It is therefore crucial that we get the concept of magnetic field right.



*Einstein solved the paradox of gravitation (The Sun at the center, Jupiter revolving around it - say) by proposing that the space itself is modified by the Sun's gravitation. Jupiter's motion is determined proximately by this modified space, and ultimately by the Sun. The paradox of magnetic field, I propose, is solved by ascribing to the space a matterless mass.*

Now, what is a "real thing"? It is either mass or energy. Those are the only real things we know. Those are the only things we can touch, feel or otherwise sense. According to Einstein's mass-energy relation, energy can be considered a part of mass. So what we need to do now is examine if magnetic field fits the most unambiguous definition of mass that we can apply to it. Remember, we are examining the proposition that *magnetic field is a mass*, and not that *magnetic field has a mass*. This distinction may seem tricky at this time, but just make a note of it.

If we are able to demonstrate that magnetic field is a mass, then it would present another conceptual hurdle: It would be an unfamiliar, *matterless mass*. The term matterless mass has been coined earlier to refer to effect of gravitation on space, for example (empty space acting like a gravitating mass on a cosmological scale). But here we are, for the first time, speaking of a mass of actual, everyday experience that is matterless. (Curiously, there is in existence an independent suggestion by Bo Lehnert that a photon at rest has a non-zero mass. And of course there is the failed idea of Geon (from John Archibald Wheeler) – a particle made of pure light gathered together to a point by means of self-gravitation.)

## CHAPTER VII

### A DEFINITION AND ITS CONSEQUENCES

*Mass* in physics is a rigorously defined quantity. When this definition is made as unambiguous as possible, whatever fits this definition is mass. The most unambiguous definition of mass is:

$$\text{Mass} = \text{Momentum}/\text{Velocity},$$

expressed as a scalar quantity (the velocity being less than the velocity of light.) Every entity that is mass must fit this definition. By the same token, any entity that does not fit is not a mass. For electromagnetic wave, which does have momentum, this definition nevertheless does not apply, since the velocity here is the velocity of light. (However, as we noted above, there is new thinking on this issue).

Notice, importantly, that this definition is independent of gravitation. By our experience and orientation, we tend to both consciously and subconsciously link mass to gravitation. We think of weighing. But an absolute definition of mass cannot depend on the concept of gravitation.

With this orientation, you are ready to go to my scientific paper, **Gravitational Mass of Magnetostatic Field**, *Astrophysics and Space Science*, vol. **239**, pp. 25-33, 1996. This paper is also included here as APPENDIX.

It was published after many rejections and rebuffs by the physics establishment. The paper is written in the simplest possible scientific language – about the level of a freshman physics course. You need to know velocity, momentum, elementary integration and differentiation, magnetic force on a current ...simple concepts of this type. To this we add a new, experimentally verified concept (also simple) recently introduced by myself and others: Magnetic force on a dielectric polarization current.

The paper provides proof that according to the above definition, magnetic field in empty space is a mass. The paper gives an expression to find out exactly how much the mass is in grams or pounds.

## **CHAPTER VIII**

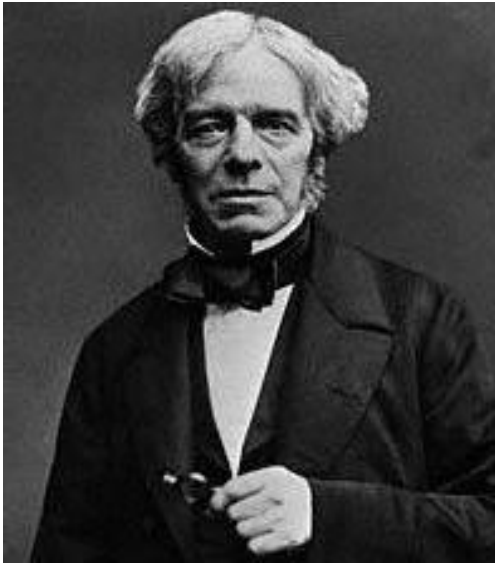
### **IF HISTORY WERE ANY GUIDE...**

It is not a good idea to look to history for support of a revisionist scientific idea. But, having fully developed the idea, one can certainly look to history for any perspectives there.

There is no indication that James Clerk Maxwell, or his contemporaries, or even those that followed them up until the advent of Quantum Theory held that the nature of electromagnetic fields had been completely understood. In fact, sporadic debates continued on this subject. It is the advent of Quantum Theory that forcibly closed an open subject to gain its own foothold. When Quantum Electrodynamics began to be formulated, the final seal had to be, and was, placed. And ever since then, this seal has been guarded by physics academics by means of haughty, authoritative pronouncements from their Bible – the electromagnetic theory textbooks. And who wrote these textbooks? The physics academics.

Physics professors and electrical engineering professors write Electromagnetic Theory textbooks. Textbook begets textbook. The lore proliferates. Thus, over the last several decades, our entire source of primary knowledge has come to consist entirely of derivative and imitative textbooks published in recent times. No one stops to think if something of fundamental value has been lost in this 'begat' process. No one (myself included) goes back to Maxwell's Dover book to study the roots of EM Theory. It is so archaic! So today we do not know and are not being told what the view on magnetic field was of the founding fathers. We are just given the politically correct view that magnetic field lines are a mathematical concept, by pedantic pedagogues who do not have the faintest idea how they are helping erase the great original thoughts. Worse yet, these textbooks are now used to keep out that which should already have been there from 'the beginning'.

Make no mistake about this: With regard to the nature of magnetic field, a dropped ball is being passed off as a played ball by today's establishment.



*Michael Faraday (1791-1867):*

***"I cannot conceive curved lines of force without the conditions of a physical existence in that intermediate space."***



*James Clerk Maxwell (1831-1879):*

***"...we cannot help thinking that in every place where we find these lines of force, some physical state or action must exist in sufficient energy to produce the actual phenomena."***

It is with great surprise and greater satisfaction that I recently learned that the founders of the concept of magnetic field lines had felt in their gut the same thing as I today prove. What is more, a new voice has now been added. In June 2006 I received

from Romanian physicist Ionel Dinu a manuscript that opens with the above two quotes from Faraday and Maxwell (This is the first time I learned about these quotes). Dinu explains that magnetic field lines cannot be just fictitious geometric lines, but that something real exists where the lines are. In his view, the field lines are a manifestation of the flow of the pervasive ether. Dinu faced rejection from the physics establishment, but fortunately for him and for science, his paper is being published (Ionel Dinu, "What's behind Faraday's Magnetic Lines of Force", *Electric Spacecraft Journal*, Issue No. 41, August 2006, pages 24-30.)



*Ionel Dinu (b. 1972) from Romania is a most remarkable thinker. He holds a Master's degree in physics. But his work already has the maturity of a deep, seasoned original thinker. About his work he says:*

**"Aether is that missing chapter in our book of natural philosophy which can lead us to understanding physical phenomena to a degree of completeness and consistency never dreamt of by human civilization."**

*Right or wrong, his process of thinking alone makes his work worthy of attention.*

The basic scientific formulation of magnetic field was completed long before the view of magnetic field as distended, large-scale, essential component of the universe emerged. This early formulation was based largely on our experience with permanent magnets and electric currents in conductors. Therefore, that formulation was based on information that was largely incomplete. There is no evidence that it was reexamined in view of the emergent picture of the magnetic universe.

# CHAPTER IX

## PARADOXES OF GRAVITATION AND COSMIC MAGNETIC FIELD

Imagine formulating gravitation solely on the basis of the falling apple, without any knowledge of planetary orbits. You would probably have the acceleration due to gravity  $g$ , but no gravitational constant  $G$  and no inverse square law. You would have no inkling about spacetime, gravitational waves etc. Imagine not reexamining that formulation in view of the knowledge of universal gravitation!

Another related historical perspective: Einstein revised the Newtonian view of gravitation, largely because he took into greater account cosmic gravitation. We might ask, who might likewise have revised the 'Maxwellian view' of magnetic field, taking into account cosmic magnetic field? Here's the interesting thing: Albert Einstein himself made forays into Electromagnetic Theory, and started asking questions about momentum and such! These were the right questions. However, the contemporary 'experts' raised such a holy hell (an acrimonious debate), that Einstein gave up on this - perhaps out of exasperation.

In the early days when physics academics were more open to admitting their puzzlements and the limitations of their understanding, a seminal Electromagnetic Theory textbook was written by J. A. Stratton. In this book, he writes this sentence: *There appears to be an inertial character associated with electromagnetic fields.*

And he leaves it at that!

# CHAPTER X

## THE SURVEYOR'S PARADOX

In my paper, one way I proposed measuring the mass of magnetic field in empty space can be compared to measuring the mass of air as follows: Take a flat surface such that you can measure the pressure of wind on it. Take a device that measures the velocity of wind (like a weather vane.) Go to a place where wind is blowing. Place the flat surface at a 90-degree angle with respect to the wind direction. Now the pressure you measure can be converted to the momentum of the wind. When you divide that by the velocity you have measured, you get the mass of air (i.e. the mass per unit volume).

You can also do this experiment if the angle were different from 90 degrees. You just have to make a trigonometric correction for the angle. However, when the angle is exactly 0 or 180 degrees, the experiment fails. It is not an asymptotic or gradual failure as you approach these angles, but a catastrophic failure exactly at these angles.

This problem can be couched in terms of a "surveyor's paradox". In a field, there are two posts A and B a distance  $d$  apart. The surveyor can stand anywhere in the field (at any point O), and measure his distance to these posts, and the angles his line of sight makes with reference to North, say. From these observations, he can calculate the distance  $d$ . The point O can be anywhere at all, as long as it is not smack on the line passing through A and B. There, his technique fails catastrophically.

What do you make of these paradoxes? Does the fact that the measurement fails in a specific case mean that all other measurements are meaningless (i.e. air has no mass, and there is no distance between A and B)? The answer is obvious. Yet, for the referee and the editors of the British Institute of Physics, the answer was YES, and on this "surveyor's paradox", they rejected my paper. See Appendix B. It is instructive as to the scientific establishment thinking.

# CHAPTER XI

## CONSIDERATIONS OF EXPERIMENTAL VERIFIABILITY

Building on the suggestion made to me by Robert Bielik of Sweden, I outline here an experiment that may be able to indirectly detect any mass of magnetic field. I posit this not so much as a detailed instruction on an actual experiment but more as a gedanken versuch.

**BASIC NEEDS:** Here are the resources needed for the experiment.

- (1) A few strong permanent magnets of different shapes, sizes, strengths;
- (2) A sensitive, fast-response magnetometer with a voltage output signal;
- (3) A variable speed motor capable of spinning the above magnets;
- (4) A compact, battery-powered laser light source (a laser pointer pen, e.g.);
- (5) A fast-response laser light detector with a voltage output signal;
- (6) A suitable oscilloscope with at least two simultaneous, real-time display channels;

Mount the motor on a rigid base with its shaft vertical, and pointing up. Extend this shaft so that the magnetic field of the motor is not a factor in the experiment. Shield the motor if necessary. On this shaft, mount rigidly a permanent magnet. Call the plane of rotation of the magnet the reference plane. The orientation of the magnet should be such that when viewed with the magnetometer located at a distance in the reference plane and hooked up to the bottom channel of the oscilloscope, the magnetic field shows the maximum variation during one cycle of rotation. In other words, the periodic curve seen on the oscilloscope should have as much “feature” as possible. The magnetometer should be placed as far away from the motor as possible without losing the signal, but not so far that feature loses its “sharpness”.

On top of this magnet, mount rigidly the compact laser source such that the beam sweeps a plane parallel to the reference plane. The angle between the laser beam and the magnet axis, both in the reference plane, should be made adjustable. Near the location of the magnetometer, set up the laser detector such that the laser beam sweeps across its aperture. On the top channel of the oscilloscope, the output of this laser detector should appear as evenly spaced spikes when the motor is in

uniform motion, with this spacing expanding or contracting when the motor decelerates or accelerates.

My theory is applied here to the magnetic field in the empty space surrounding the magnet. If the field has a mass, then there is an inertia associated with the rotating magnetic-field structure, no matter how small. There is also an inertia associated with the rotating shaft-magnet combination.

Consider the motor speeding up from rest. As soon as a torque is applied to the motor, it is instantaneously transmitted to the magnetic field mass in empty space. The latter, having nearly zero inertia, will respond immediately. However, the shaft-magnet assembly will respond according to its own mass. Thus, one expects a lag between the magnetic field structure and the magnet.

Therefore, when the magnet is speeding up or slowing down, one expects to see a lateral shift between the top and the bottom traces on the oscilloscope screen. One hopes to detect this inertia differential, rather than detect the very small mass of the magnetic field.

Since, according to the conventional theory, magnetic field is only a mathematical definition of the force due to the magnet, no such shift is predicted.

The reference state for the measurement is obtained when the motor is in uniform motion. In this state, examine the bottom trace from the magnetometer, and identify a fiduciary mark such as a discernible peak or trough or a zero-crossing. Then go back and adjust the orientation of the laser source so that when the motor is back in uniform motion, the spike from the laser source in the top trace lines up exactly with the identified feature. Overlap the two traces.

Now, if the magnetic field has an inertia, then, during slowing down or speeding up of the rotation, the spike and the feature will separate laterally.

Some difficulties are foreseeable even before doing the experiment. The transient time shift between the top and the bottom traces may not be discernible with naked eyes. If the time base is greatly expanded, definition of the bottom trace may be lost. If it is greatly compressed, the shift will not be visible. One has to think ahead how to address this situation. One might be able to increase the rate of deceleration by braking the motor, for example. The experiment should be repeated with different magnets, different uniform motor speeds, and different shaft-to-magnetometer distances, and different masses of the rotating shaft-magnet assembly.

## CHAPTER XII

### CLOSING THOUGHTS

This may not be entirely pertinent, but an amusing thought came to my mind. If one cut short a budding idea or investigation because one found oneself reduced to the debilitating “straight-line paradox”, much of the modern civilization would not exist. Consider the piston – whether in an old-fashioned steam locomotive or a modern internal combustion engine. When the piston was first invented, one could have dismissed it by saying: It only moves along a straight-line; so we cannot get any useable rotary motion out of it. Where would the civilization be today? Alternatively, one could “move”: Get off one’s rear end and do something to advance beyond being debilitated by this paradox. Because somebody or some people did this way back then in the case of the steam engine, the civilization is where it is today.

The above story of the surveyor’s paradox is important in this light as well. It illustrates the very basic (or rudimentary) nature of the idea that we are dealing with here. In the last analysis, if magnetic field were a mass and if we missed this foundation of physics because of a logical flaw in our thinking, the flaw has to be this simple. As you will note, my proof that magnetic field is a mass is simplicity itself.

A hundred years ago and before then, physics was natural philosophy. The thinkers then thought deeply and broadly in the manner of savants. Then they used the simplest of mathematics to lay down the lasting foundation of physics. They had quiet wisdom. What they did has stood the test of time – like the pyramids. Nothing of that magnitude has occurred in the past several decades. Over those decades we have seen the rise of the new breed of leaders, the mathematical technicians. They have loud expertise. They are fabricating high-rise apartment buildings and shopping malls and multi-story parking structures. What I have described above is in the realm of natural philosophy. The mathematics here is minimal. In this sense, the response to my work from today’s leaders is not surprising. Indeed, any physicist today who is truly a natural philosopher would spontaneously come to apply the most basic premise of an inquiry, as enunciated by Marcus Aurelius Antoninus (121-180 AD), to distended and pervasive static magnetic field in the vastness of the universe:

*What is it in itself?*

*What is its nature?*

# **APPENDIX A**

## **IMAGES**

A few graphics I placed on the Internet to explain the idea -

# A NEW VIEW OF MAGNETIC FIELD

It is a theater in the sky...

- Wallace Stevens

Image courtesy: [www.geo.mtu.edu/weather/aurora/images/aurora/jan.curtis/](http://www.geo.mtu.edu/weather/aurora/images/aurora/jan.curtis/)



**For any particular thing, ask,  
What is it in itself?  
What is its nature?**

Marcus Aurelius, Meditations

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**THE-FOUNDATION-IS-THE-FRONTIER SERIES**

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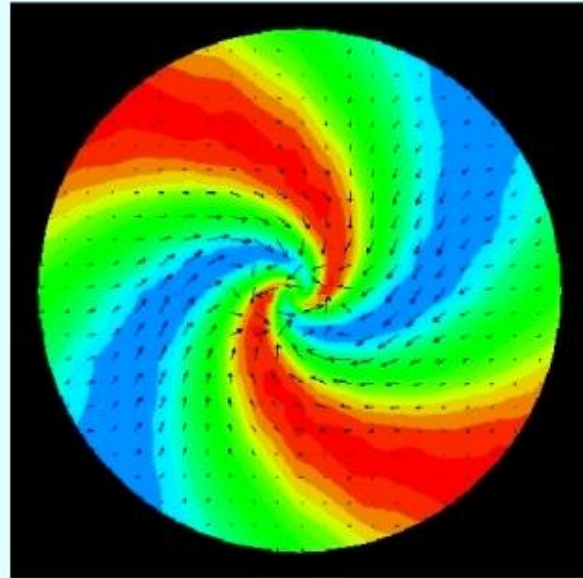
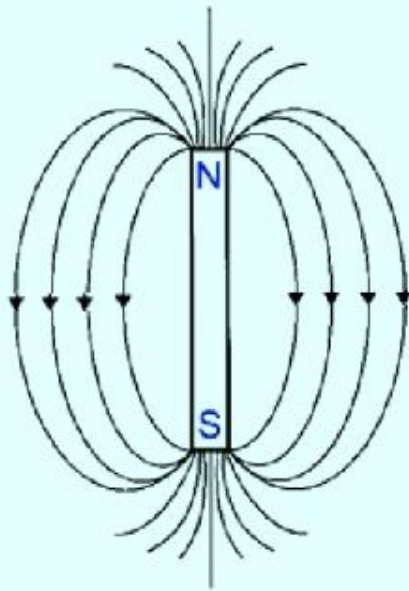
Essays on: **Physics in the Twenty-first Century**

**Bibhas De**

# MAGNETIC FIELD IN EMPTY SPACE

**What is it?**

**Did we get it right?**



[www.aip.de](http://www.aip.de)

**Magnetic field due to a bar magnet, and the galactic magnetic field.**

In going from the former to the latter, we still kept the notion that magnetic field is just a mathematical description, that there exists no real effect corresponding to a magnetic field line at its location.

**They got that right!**



[www.bhrc.ac.ir](http://www.bhrc.ac.ir)



[wikimedia.org](http://wikimedia.org)

**Earth's gravity and universal gravitation.**

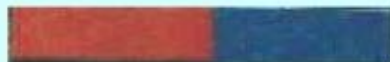
In going from the Earth's gravity to universal gravitation, they figured out that corresponding to the gravitational field at any point in space, there exists a real effect.

[www.bibhasde.com](http://www.bibhasde.com)

# MAGNETIC FIELD IN EMPTY SPACE IS A MASS

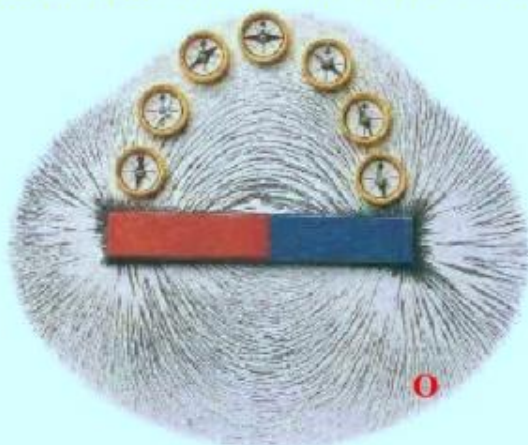
## What does this statement mean, exactly?

(a) First consider a bar magnet that has not yet been magnetized. It has a mass  $m$ . At a point such as X, there is no effect due to the bar.



X

(b) Now consider that it has been magnetized. At the point O now there is a definable magnetic field which can be detected and traced by means of small compass needles. What does this magnetic field in empty space consist of? What is it *made of* at O?



[Images courtesy: [www.school-for-champions.com](http://www.school-for-champions.com)]

**PRESENT VIEW:** The magnetic field at O is purely a mathematical definition that helps us describe the effects of the field. At O, there is present nothing real. Since the bar has been magnetized, some energy has been added to it. So its mass will increase by a small amount  $\Delta m$  because of the mass-energy relation. Where is this *extra* mass located? Obviously, it is located *in the bar* – and *not* distributed in the empty space around it.

**MISGUIDANCE:** When I presented my new idea that there is a real presence at the point O, I was told by establishment referees that it is already well-known. They assert that the extra mass  $\Delta m$  is well-known to be distributed in empty space around the magnet – and I am re-inventing this. This assertion is both untrue and unhelpful.

**MY NEW IDEA:** I say that at the point O (and everywhere in space) there is present an invisible but real mass which we name 'magnetic field'. And this mass does not come from the  $\Delta m$  of the mass-energy relation in the aforementioned (mistaken) way. Rather, it is obtained from the first principles of mass and momentum and the observed properties of magnetic field, and differs from  $\Delta m$ . This is a radically new foundation of physics – one that was missing thus far, but one that was suspected to exist by Michael Faraday and James Clerk Maxwell.

[www.bibhasde.com/magmass.html](http://www.bibhasde.com/magmass.html)

# BIBHAS DE'S MATTERLESS MASS

## THE ESSENCE OF MAGNETIC FIELD: WHAT IS IT?

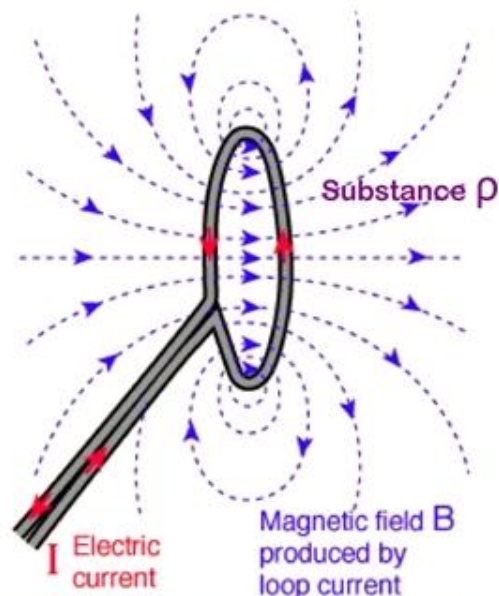


Image courtesy: <http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/imgmag/curloo.gif>

**Magnetic field in any location in empty space derives from a matterless (or "invisible") mass present at that location (De 1996). What can we say about this newly discovered substance, having mass  $\rho$  per unit volume?**

**Although we know nothing about this substance, we know the properties of magnetic field – and from there we can work back to reach some conclusions.**

**First, the substance is FLUID. This is so because when a current loop is energized, the substance flows out from the battery to the surrounding space. When it is de-energized, the substance re-enters the battery.**

**Second, the substance is COMPRESSIBLE. This is so because there can be varying quantities of this substance filling a unit volume.**

**Third, it is necessary to assign to this substance a VECTOR character so that magnetic field will have a sense (arrow). A flowing fluid, for example, has a vector character. But we do not assume *a priori* that our new substance is flowing – just that it somehow has a vector character, to be explored later.**

**How does  $\rho$  relate to our familiar concept of the magnetic field  $B$ ? Constants aside, this seems tentatively to be the relation:**

$$\mathbf{B} \sim \text{curl curl} (\text{grad } \rho)$$

**- giving new physics meaning to an old, tried-and-true technical definition!**

B. R. De, Astrophysics and Space Science vol. **239**, 25-33, 1996.

[www.bibhasde.com/magmass.html](http://www.bibhasde.com/magmass.html)

# **APPENDIX B**

## **A REFEREE REPORT REJECTING THE PAPER**

Ms. Title: The Mass of Magnetostatic Energy: A Hypothesis

Submitted to: *Journal of Physics A: Mathematical and General*

Received Date: 6 February 1995

Ms. No. : A/62489/LET

### **REFEREE REPORT:**

The author points out an interesting discrepancy of a factor of 2 between the usual expression for magnetostatic energy and a seemingly natural alternative. However the hazards of ascribing motion , or not, to the energy of a uniform magnetic field are shown up by considering motion *along* the field direction, in which case the Poynting vector is zero in all frames, paradoxically. These are good topics for coffee table discussions rather than for publication, in my view.

## **APPENDIX C**

### **THE PAPER**

Gravitational Mass of magnetostatic field by B. R. De, *Astrophysics and Space Science*, vol. 239, pp. 25-33, 1996.

This paper was published in 1996. Now it is 2021. I have not seen a single citation of it anywhere.

# GRAVITATIONAL MASS OF MAGNETOSTATIC FIELD

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**Abstract.** Maxwell's displacement current equation is interpreted in the light of recent work to show that static magnetic field in free space should have a colocated and contemporaneous mass that is neither embodied in, nor can be anticipated from, the mass-energy relation. Thus magnetostatic field in the universe represents an 'invisible' mass. Some consequences are discussed.

## 1. Introduction

Magnetostatic fields of varying strengths permeate much of the mostly empty space in the universe – from the weak fields in the galactic and intergalactic mediums to the ultrastrong fields in the vicinity of neutron stars. Aspects of the energy in a static magnetic field discussed recently (De, 1993, 1994a) show that this reservoir of energy, even in far locations not in instant communication with the source of the field, can be locally drawn down and partially transformed to other forms such as heat added to a fluid (De, 1994b). The heat energy causes the mass of the fluid to increase in accordance with the mass-energy relation (see e.g., Møller, 1966), indicating a source of available mass in the original reservoir. This raises the question, going beyond the mass-energy relation, as to whether magnetostatic field in absence of matter, i.e. in vacuum, does not itself possess a measurable mass. This point is developed here by interpreting Maxwell's displacement current concept. While the resultant mass is much too small to be of interest in terrestrial applications, its place in astrophysical situations merits discussion.

The present paper suggests a colocated and contemporaneous mass of magnetostatic field, and not an *equivalent* mass in the sense that the field energy can be obtained by consuming mass. The mass-energy relation *does not* assign a colocated and contemporaneous mass to magnetostatic energy in empty space. It will be shown further that the result obtained in the present paper cannot even be anticipated from this relation. In the Electromagnetic (EM) Theory, although it has long been noted that there is an inertial character associated with EM fields (see, e.g., Stratton, 1941), there exists no specific suggestion that a static magnetic field in vacuum has a colocated mass.

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## 2. Definition of Inertial Mass in Empty Space

The underlying idea of an actual and observable mass residing in perfect vacuum does not appear to have been put forth before. It may be noted though that even in the mass-energy relation the mass depends only on the amount of energy, and not on any material property (e.g., mass, density, composition) of the body to which the energy is added. This concept already advances a long way towards that of a mass without material content. It is necessary, however, to adopt a legitimate definition of mass that can be applied to empty space. It is most convenient to begin the discussion by considering inertial mass, and then to generalize the discussion to gravitational mass.

A workable definition of inertial mass that can be adopted to empty space happens also to be in one view the most unambiguous definition of mass in physics: An inertial mass possesses simultaneously a measurable momentum and a measurable velocity that is less than the velocity of light (Kompaneyets, 1965). The quantitative definition is that the inertial mass equals the scalar ratio of the momentum to the velocity. Thus, to measure a mass one must consider it to be in motion.

The above definition is consistent with the definition of mass as the scalar ratio of force to acceleration. However, the momentum-based definition can blend more easily with the relevant concepts of classical EM Theory.

## 3. Measurement of Inertial Mass in Empty Space

It is next necessary to specify a way to measure the momentum contained in EM fields in empty space. This can be done by employing a device termed a force-measuring antenna (De, 1993).

A force-measuring antenna (FMA) is quite simply an electric field sensing antenna or conductor mounted on a force transducer that senses any mechanical force on the antenna. Beyond serving as a measuring implement, this device provides a crucial conceptual foundation for the present discussion: If the transducer senses a mechanical momentum, then the momentum carried by the incident EM fields is by definition a mechanical momentum. By establishing this fact, the device permits one to go beyond a certain long-standing paradox (see Section 5) of the EM Theory, and explore areas that have not been traditionally explored.

## 4. Definition of Reference Frames

The following discussion makes use of a certain magnetic force on a pure dielectric (Brevik, 1976) that has occupied an obscure place in the development of the EM Theory. It has been suggested that the study of this force can help complete certain incompletenesses in this development (De, 1988, 1993). Initially, a unit cube of a lossless, linear dielectric material of mass  $\rho$  and polarizability  $\chi$  is considered. It

is accelerating under an external force across a uniform static magnetic field  $B_0$  in vacuum, with one edge of the cube parallel to the field and one face perpendicular to the direction of motion. The source of this magnetic field defines the rest frame of the discussion. The cube has a velocity  $\mathbf{v}$  ( $v \ll c$ , the speed of light) and an acceleration  $\mathbf{f}$ , and constitutes the moving frame.

Two experiments will now be considered: An experiment in the moving frame by Observer A stationed on the dielectric cube platform, and one in the rest frame by Observer B when the dielectric is replaced by an infinitely conducting material.

### 5. Measurement in the Moving Frame

In the moving frame there is an electric field  $\mathbf{E} = \mathbf{v} \times \mathbf{B}_0$ . If  $\mathbf{B}$  is the induced magnetic field ( $B \ll B_0$  for simplicity) in the same frame, then  $\mathbf{E}$  and  $\mathbf{B}$  satisfy Maxwell's displacement current equation:

$$\nabla \times \mathbf{B} / \mu_0 = \chi \epsilon_0 \dot{\mathbf{E}} + \epsilon_0 \dot{\mathbf{E}} \quad (1)$$

where  $\mu_0$  and  $\epsilon_0$  are the magnetic permeability and the dielectric permittivity of vacuum. The time-variation arises during acceleration. It is now noted that the vacuum displacement current, the second term on the right hand side, was originally predicted by Maxwell by extending the material current (the first term) to vacuum, and was later experimentally verified. Taking the cross product of the above equation with  $\mathbf{B}_0$  one obtains

$$(\nabla \times \mathbf{B}) \times \mathbf{B}_0 / \mu_0 = \chi \epsilon_0 \dot{\mathbf{E}} \times \mathbf{B}_0 + \epsilon_0 \dot{\mathbf{E}} \times \mathbf{B}_0. \quad (2)$$

The first term on the right hand side is a theoretically predicted and experimentally verified mechanical force on a dielectric (Brevik, 1976). By invoking Maxwell's reasoning (i.e., by extending the dielectric force to vacuum), the presence of a vacuum force term could be predicted. However, such a term has followed naturally from the vacuum current, and can be written as the time-rate of change of a momentum density

$$\mathbf{G}_0 = \epsilon_0 \mathbf{E} \times \mathbf{B}_0. \quad (3)$$

This quantity has long been described as an abstract *electromagnetic* momentum to distinguish it from the mechanical momentum contained in the first term on the right hand side of Equation (2). However, as mentioned before,  $\mathbf{G}_0$  has been shown to be observable as a time-varying mechanical momentum using an FMA. If  $\mathbf{G}_0$  can be observed as a mechanical momentum, then it is by definition a mechanical momentum. In this way the present discussion can circumvent the unresolved historical controversy in the EM Theory regarding what is electromagnetic momentum and what is mechanical momentum (*op. cit.*).

Observer A in the moving frame can measure his acceleration  $\mathbf{f}$ , and the time derivative of  $\mathbf{G}_0$ . By making these measurements for several values of  $\mathbf{f}$ , he will find (e.g., by making a graphical plot of the observations) that

$$\dot{\mathbf{G}}_0 = -C_1 \mathbf{f} \quad (4)$$

which yields a numerical value for the constant  $C_1$ . He can now integrate the above equation to obtain

$$\mathbf{G}_0 = -C_1 \mathbf{v} + \mathbf{C}_2. \quad (5)$$

## 6. The Meaning of $C_1$ and $C_2$

The vector integration constant  $C_2$  is now interpreted to be the value of  $\mathbf{G}_0$  when the observer is at rest, and can be set equal to zero as a choice. This leads A to conclude that the momentum flow  $\mathbf{G}_0$  is due entirely to the velocity of his frame, or that the velocity  $\mathbf{v}_0$  and the acceleration  $\mathbf{f}_0$  of the momentum flow in his frame are equal to  $-\mathbf{v}$  and  $-\mathbf{f}$ , respectively. Hence

$$\mathbf{G}_0 = C_1 \mathbf{v}_0 \quad (6)$$

which is the unambiguous definition in physics of an inertial mass  $C_1$ . This quantity is therefore an intrinsic mass residing in vacuum, and owes its presence to the magnetic field  $\mathbf{B}_0$ . Upon combining Equation (3) with the above equation, one finds

$$C_1 = \epsilon_0 B_0^2. \quad (7)$$

## 7. Magnetic Field and Motion

The experiment described above is somewhat analogous to the following situation: An observer W accelerates through still air. He therefore feels a gust of wind. By measuring the ram pressure of the wind on a plate held *perpendicular* to the direction of motion, W can determine the momentum of the wind and hence the mass density of air.

Returning to Observer A, one can now consider motion in arbitrary directions with respect to the magnetic field. By orienting the FMA for peak signal, this observer can determine the direction of the momentum flow. Since he knows the direction of the magnetic field, he can make allowance for the angle between the two directions in Equation (4). He will then measure the same value of the mass density  $C_1$  regardless of the direction of travel. This shows that the mass of magnetostatic field is independent of the directional nature of magnetic field.

The singular exception to this arises when the motion is exactly parallel to the magnetic field direction. Here the momentum  $\mathbf{G}_0$  and the velocity  $\mathbf{v}_0$  of the momentum flow are both zero, so that  $C_1 = 0/0$  becomes indeterminate. Such indeterminacy related to motion parallel to a magnetic field has been considered in

traditional EM Theory as a paradox, indicating the hazard of assigning motion (or not) to the magnetic field. However, the singularity here is not an issue of the EM Theory in particular, but of measurement science in general.

First, the case of Observer W performing a non-EM measurement can be considered. If, instead of holding his plate perpendicular (i.e. at 90 degrees) to the direction of travel, he holds it at an arbitrary angle and makes an allowance for it, he always measures the same mass density of air regardless of the angle. However, the mass becomes indeterminate if the angle is exactly 0 degree. This does not disprove that air has a mass. It simply means that for this particular configuration, the measurement technique fails. Many such instances of non-EM measurements can be described.

Second, one can consider the instance of Observer A performing an EM measurement different from the one described. He makes a noncontroversial measurement of the magnetostatic *energy density* which is an established quantity of physics. He measures the magnitude and the direction of the motional electric field  $\mathbf{E}$  using conventional instruments, calculates the magnetic field upon taking into account the angle between this  $\mathbf{E}$  and the known velocity  $\mathbf{v}$ , and then reports the energy density  $U_0 = B_0^2/2\mu_0$ . He measures the same value of  $U_0$  for every direction of motion except the singular case when he travels exactly parallel to the magnetic field, where the energy density becomes indeterminate. This case does not render the energy density meaningless, nor says that it is nonexistent, nor assigns any directionality to it.

There is nothing inexplicable or paradoxical about the above instances. The observer's remedy in all such instances is to slightly perturb the angle in question if he encounters the indeterminacy. The same comment applies also to the present discussion.

## 8. Measurement in the Rest Frame

Next, the viewpoint of Observer B is considered. The dielectric cube is now replaced by a cube of infinitely conducting material. The cube is then assumed to be attached to the rest frame by a spring having a spring constant  $k$ . It is an 'ideal' spring in that it is massless, and electrically and magnetically inert. The instantaneous position of the cube is  $\mathbf{x}$ , and the magnetic field  $\mathbf{B}_0$  is perpendicular to the  $x$  axis. In absence of the magnetic field, the time period of mechanical vibration of the system is

$$T = 2\pi\sqrt{\rho/k}. \quad (8)$$

Knowing  $k$  and measuring  $T$ , B can find the inertial mass  $\rho$ .

When the magnetic field is present, the equation of motion of the cube becomes

$$\rho\ddot{\mathbf{x}} = -k\mathbf{x} - \varepsilon_0\dot{\mathbf{E}} \times \mathbf{B}_0 \quad (9)$$

which can be solved to find that the time period now is

$$T_B = 2\pi \sqrt{(\rho + \rho_0)/k} \quad (10)$$

with

$$\rho_0 = \epsilon_0 B_0^2. \quad (11)$$

Upon measuring  $T_B$  and knowing  $k$ , B finds that the inertial mass of the cube is  $\rho + \rho_0$ . Since the experiment utilizes a conservative (lossless) medium, the slowing of the time period cannot be ascribed to any losses. Since the increase in the mass of the cube is independent of the original mass, the measured value of  $\rho_0$  remains unchanged as  $\rho$  is made arbitrarily small. Thus the above experiment amounts to a clear and unambiguous measurement of the mass density of the magnetic field. The same comments about the directionality of the magnetic field apply to the above discussion as in Section 7.

Thus Observers A and B, in different frames of reference and pursuing different measurement methods, both come to the same absolute conclusion: Magnetostatic field in vacuum has a colocated and contemporaneous mass in accordance with the established definition of mass in physics. It follows that

$$\rho_0 \equiv C_1. \quad (12)$$

## 9. Generalization to Gravitational Mass

The discussion so far has dealt with inertial mass. Since the inertial mass and the gravitational mass are one and the same (Cf. Møller, 1966), the mass in Equation (12) can be treated as gravitational mass. It is desirable, however, to have an independent proof to support this identification in the case of the newly introduced mass that resides in empty space. To do this, one can consider a physical circumstance where both the inertial mass and the gravitational mass are simultaneously manifest.

This is indeed the case with a simple pendulum. The cube of Section 8 is now assumed to be the bob of this pendulum, with  $B_0$  being the Earth's magnetic field, assumed horizontal. The motion of the bob is horizontal, and perpendicular to the magnetic field. If  $\rho_G$  is the gravitational mass of the bob,  $g$  the acceleration due to gravity, and  $l$  the length of the pendulum, then the equation of motion of the pendulum is

$$\rho l \ddot{\theta} = -\rho_G g \theta - \epsilon_0 l \ddot{\theta} B_0^2 \quad (13)$$

where  $\theta$  is the angular displacement of the pendulum, assumed small. Since the time-period of the pendulum cannot depend of the gravitational mass of the bob, it follows that

$$\rho_G = \rho + \rho_0, \quad (14)$$

confirming that  $\rho_0$  is a gravitational mass residing in empty space.

### 10. $\rho_0$ and the Mass-Energy Relation

Attempts to connect the result of this paper to the mass-energy relation face the following difficulty: This relation applies only to energy *that is added to a material medium*. The mass-energy relation does not assign a colocated mass to pure magnetostatic energy in vacuum. Thus there is no basis for a direct intercomparison between this relation and the result of the present paper. This also means that the result is not in conflict with the mass-energy relation.

If one were to conjecturally extend the mass-energy relation to vacuum without regard to the unwarranted nature of this procedure, one would equate the magnetic energy density  $U_0 = B_0^2/2\mu_0$  to the quantity  $\rho_{me}c^2$ , where  $\rho_{me}$  is the mass density anticipated from the relation. This results in

$$\rho_{me} = \epsilon_0 B_0^2/2 \quad (15)$$

which differs from  $C_1$  or  $\rho_0$  by a factor 2. This shows that the result of Equation (7) or (11) cannot even be anticipated from the mass-energy relation. One may wish, for whatever reason, to preserve the mass-energy relation even in vacuum by interpreting the factor 2 as a discrepancy between  $U_0 = B_0^2/2\mu_0$  and a seemingly natural alternative energy density,  $U_0 = B_0^2/\mu_0$ . This duality, however, would lead to legitimate paradoxes and violations. The conclusion then is that the result of the present paper is neither embodied nor contemplated in the mass-energy relation. It may be that mass, and not energy, is the true attribute of a static magnetic field.

When magnetostatic energy is drawn down and partially transformed to heat energy of a fluid (De, 1994b) with resultant increase in the mass of the fluid, the mass-energy relation does of course apply to the added *heat* energy and the increase in mass. However, this does not lead to Equation (15).

The general result of the present paper can be experimentally verified by weighing a superconducting coil of inductance  $L$  with and without a steady current  $I$  flowing through it. According to the present paper, the mass of the coil should increase by a quantity  $\Delta m$  when energized, where

$$\Delta m = \int \rho_0 dV = LI^2/c^2, \quad (16)$$

and where the volume integral extends substantially over the region of the magnetic field in the empty space next to the coil. It may be noted that this test does not require the magnetic field or the observer to be in motion. A verification of the above equation amounts to a verification of the following conclusions:

- (i) Magnetostatic field in free space has an actual mass;
- (ii) There exists in the universe a mass without material content; and
- (iii) These results are not contained in the mass-energy relation.

## 11. Applicability Considerations

Since in general the mass of magnetostatic field is very small, it is best compared with the lightest familiar component of the material mass in the universe, namely, electrons. It is convenient to express the mass density of magnetostatic field in terms of the equivalent number of electrons per cubic centimeter:

$$N_e \sim 10^5 B_{og}^2 \quad (17)$$

where the magnetic field now is in units of gauss. This relation permits one to compare  $N_e$  with the electron number density  $N_e$  in various astrophysical situations. It may be noted that while in local concentrations of magnetic field such as a sunspot the ratio  $N_e/N_e$  can far exceed unity, for the mean galactic medium the ratio is quite small ( $\sim 10^{-4}$ ). Thus, while magnetostatic field in the universe does represent an invisible mass, it is much too weak to account for the so-called cosmological dark matter (Saunders *et al.*, 1991).

Magnetic fields in excess of  $10^{12}$  G are known to exist in the largely empty space near neutron stars where exotic physical processes are thought to be operative (Harding, 1991; Beskin and Gurevich, 1993). Here the values of  $N_e$  exceed  $10^{29}$  cm $^{-3}$ . The mass density  $\rho_0$  far exceeds that due to the disperse subatomic particles in the region. This fact needs to be incorporated in the physics of neutron star atmospheres. One might consider if the magnetic field is not so intense in part because the field has been compressed by the gravity of the star. This suggested process is distinct from the magnetohydrodynamic compression of magnetic field when a body of conducting gas gravitationally collapses.

## 12. Remarks

Many questions will no doubt arise in attempting to reconcile the mass  $\rho_0$  with the known properties of magnetostatic fields. For example, a magnetic field is dependent on the frame of reference in which it is measured so that  $\rho_0$  will change accordingly. This means that in a distended region of magnetostatic field the mass will appear redistributed in space when the observer shifts from frame to frame. Second, if the magnetic field is caused to vary faster and faster with time so that the magnetostatic energy gradually assumes the form of EM radiation, then  $\rho_0$  must gradually vanish. This is because photons which constitute the radiation have no rest mass. This implies a functional relationship between  $\rho_0$  and the period  $\tau$  of time variation,  $\rho_0(\tau)$ , that may be worth exploring in the context of the study of the essential nature of vacuum itself (Boyer, 1985; Podolnyi, 1986; Puthoff, 1989). Third, one may wonder as to the mechanism by which a distended region of magnetic field (devoid of matter, say) in the universe might gravitationally attract a material mass (e.g., a galaxy). This question may be answerable once the mechanism of gravitation between two material masses is understood. In this context, the

problem of gravitational support of a planetary dipole magnetic field also needs to be addressed. Finally, Equation (14) represents a rudimentary connection between magnetism and gravitation, and as such may be of interest in the search for a theory unifying Electromagnetism and Gravitation.

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